Towards a Hybrid Quantitative-Qualitative GIS

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1 Background

Since ancient times, men had the necessity to catch, model and store information. An important part of the information field is the one concerned with geographical and spatial matters. In general, geographic (or geospatial) information is created by manipulating geographic (or spatial) data. Nowadays, geospatial information can be stored, manipulated and queried within special informatics systems named GIS (Geographic Information System).

1.1 Geographic Information Systems

GIS applications are tools that allow users to create interactive queries, analyze spatial information, edit data, maps, and present the results of all these operations.

Within standard GISs, there are two methods widely used to store data: Raster and Vector. Both of them provide a geometric representation of space, which is unable to provide an extrinsic description of all those relations and features which are contained in the spatial information concept. Although geometric models are based on a really sound theory, permitting to accomplish a big range of spatial analysis, it takes some efforts to query a GIS by some qualitative requirements.

1.2 Qualitative Models

An alternative to geometric models are qualitative models: special kind of models that are successful in representing the reality by its qualitative nature. A qualitative model formally specifies features, properties and relationships for the entities of the modeled domain, as well as rules and constraints such entities are constrained by. A particular subset of qualitative models consists of all that models that deal with spatial or spatio-temporal aspects. One qualitative model, usually, focuses on representing one specific fundamental spatial feature/relation, i.e. direction and orientation [1, 2], relative position [3], topology [4] etc. Some qualitative models, however, deal with features that could be defined as target-oriented, namely, certain spatial properties whose analysis is useful to achieve a certain purpose.

Iwasaki [5] describes the goal of qualitative approaches as follows: *"Broadly speaking, qualitative-reasoning research aims to develop representation and reasoning techniques that will enable a program to reason about the behavior of physical systems, without the kind of precise quantitative information needed by conventional analysis techniques such as numerical simulators."* In another way I would say that qualitative reasoning emulates human reasoning using the power of logic and symbols. Especially, qualitative models allow to represent space in a more human-like way.

2 Research Motivation

People often use qualitative spatial thinking and reasoning in everyday life [6, 7]; however, although current commercial GISs mainly support quantitative/location-based spatial queries furnishing geometric answers, they provide really weak means to satisfy qualitative queries.

If a GIS would explicitly include the storage of various qualitative relations, it would provide a powerful instrument for operations and searches based on them, highly improving time performances. Indeed it would be possible to reduce efforts that today are needed to translate from qualitative representations (typically human) to mathematic/geometric representations (standard GIS).

Furthermore, users would be furnished with a high power system, able to satisfy more human-like requests. The system would become much more user-friendly leading to a range of novel kinds of spatial analyses that are impossible to imagine nowadays.

The intrinsic properties of the system would also lead to the possibility to directly collect and store qualitative data avoiding a specific geometric description. Nevertheless it would be possible to reconstruct a geometric approximation directly from qualitative relations if sufficient qualitative information is available in the system.

By better accommodating the human requirements, qualitative models will also contribute toward the greater utilization of GIS technology.

3 Research Target

Prompted by an analysis on nowadays GIS functionalities and limitations as discussed previously, and by results and abilities of cognitive science and qualitative models and reasoning, I imagined a hybrid GIS system where capabilities of both quantitative and qualitative models are available together. The main idea is to empower a standard quantitative GIS by a qualitative relations storage layer, able to manage qualitative spatial analysis.

3.1 HQQ GIS Overview

At a conceptual level such a system has the shape of a multi-tier database for (geo)spatial data, having at a first level the quantitative/geometric representation of the space as a standard GIS. Above it lie several Qualitative Storage

Units (QSU) related in a network/graph scheme that will take care to store qualitative relation subsisting among geometric objects. A manager engine will take care of the whole structure; it will contain a querying engine as well as a UID (Update Insert Delete) engine that will deal respectively with the data retrieval and update, insertion and delete tasks. A rough sketch of the conceptual structure is depicted in Fig. 1 where edges between QSU represent conceptual connections for the stored information.

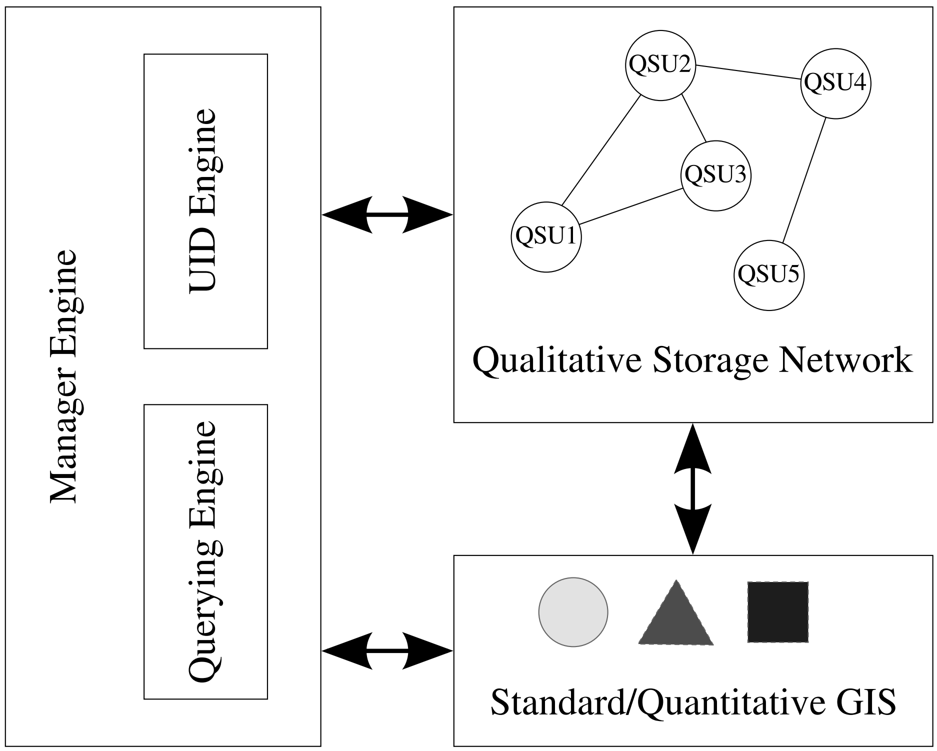

Fig. 1. HQQGIS: a rough conceptual schema

3.2 Proposed Methodology

In order to reach the objective, it will be necessary to identify a set of fundamental qualitative spatial relations. Such a set has to be able to describe salient points of qualitative spatial analysis. Subsequently, for every of the collected characteristics the best fitting qualitative model must be choose. The qualitative layer will have to be grounded on such qualitative model set. At this point, a common formalism to describe the qualitative models has to be detected. By the description of all the models trough the same formalism, it will be possible to identify and abstract in common Qualitative Storage Units the common factors among models in order to reduce data redundancy within the system, as shown in Fig. 2. Dotted lines represent connection paths between QSUs that together describe a unique qualitative model (thus they directly come up from the splitting operation), instead solid lines represent conceptual connections among different qualitative aspects (and thus models). As it is possible to observe, information furnished by a Qualitative Model (QM) could be split within several Qualitative Storage Units. Now the conceptual connections among different models (solid lines) have to be made explicit by their meaning through a formal method. Finally, one must develop a methodology to interface with the underlying quantitative layer.

For the realization phase, robust data structures have to be detected in order to make the network concrete. Such structures have also to be efficient for the operations will be necessary to satisfy. Later the UID engine can be drawn and developed: it will have to take care that modifications in the GIS layer will be mirrored on the qualitative one. Lastly, an intelligent querying engine will be developed, able to analyze a query in order to find out the best pattern within the whole structure (even the quantitative part) to retrieve information required.

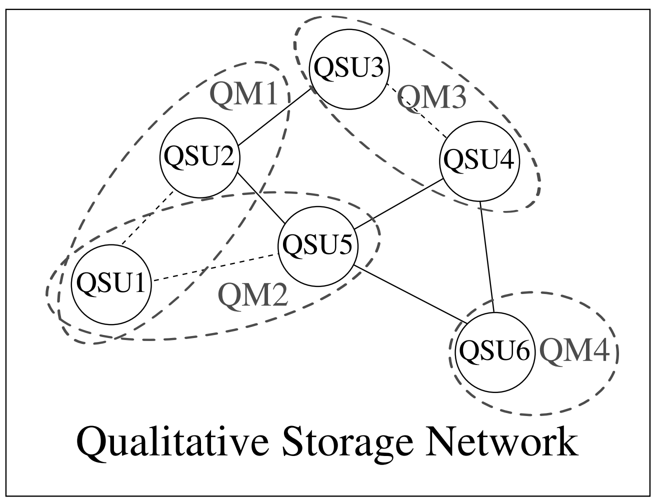

Fig. 2. Qualitative layer - common features grouped together

3.3 Personal Focus and Concrete Approach

I want to focus my research on qualitative representations of spatial data and on the querying engine.

I will study qualitative spatial models in order to define a minimal group of them, choosing between the most stable and successful. Each model will represent different spatial characteristics so that their totality can cover a wide range of spatial features and relations. Later, such a group will be complemented by models capable of representing relations of interest for specific aspects of spatial analysis.

Building on the ideas underlying the Semantic Web [8] and the Semantic Geospatial Web [9] and on ontological principles in general [10, 11], I will look for a suitable spatial ontology. First of all I will choose a top-level ontology like DOLCE [12] or BFO [13] and, according to it, I will adapt a spatial ontology to define the spatial concepts selected in the previous phase. The top-level ontology will provide a common language for the specification and hopefully will drive up common aspects to pop up. Therefore, I will start describing one qualitative model and, subsequently I will add to the ontology new specifications from other models. At the end I would obtain a complete definition of qualitative features and semantic paths between them that will be directly mapped into the qualitative network structure.

Later I will have to choose the most efficient data structures for data storage.

I want then develop a semantic model in order to obtain a reasoning system able to deal with the qualitative storage network. The querying engine will lie on such a model. It will indeed be able to process semantic queries, breaking them into several sub-queries that will be addressed towards the most properly Qualitative Storage Unit within the network, basing on their semantic request.

4 Further Work

Due to the fact that in my research I will not cover in details the connection between quantitative and qualitative layers, a future direction would be to deeply analyze such an aspect. Another interesting work could be to demonstrate whether it is possible to get a geometric approximation directly out of stored qualitative relations and, whenever it should be possible, to develop approximation methodologies.

Furthermore inconsistency among data, either within the quantitative side, as well as in the qualitative network or between the two layers is a crucial point that will need to be treated in order to get a working system. Again, integration of different data sources on the quantitative tier as well as communication among different GISs will have to be accomplished.

Lastly the natural language interpretation would highly improve the utilization capacities of the system, making possible to human being to ask for geospatial information in them own language.

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